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Commentary

Spatial variation of soil properties relating to vegetation changes

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Abstract

Bekele and Hudnall provide an interesting perspective on the spatial variation of soil chemical properties in a natural area undergoing transition from prairie to forest. Their focus is on the unique calcareous prairie ecosystem of Louisiana where prairie remnants are being encroached upon by the forest, primarily eastern red cedar (*Juniperus virginiana* L.). Bekele and Hudnall were especially interested in investigating any differences in spatial variability among similar sites and in documenting the scale at which the variability occurs. Geostatistical methods have been used to describe and model spatial patterns in soil data for more than 20 years. The accessibility of user-friendly geostatistical software packages has increased the use of spatial analysis of soil's data but carries the risk that these tools are used without due consideration of the underlying theory, especially in the field of semivariogram modeling or recommended good practices. The feedback between plant community composition and species distribution and soil properties in natural systems has promise to provide enhanced insight into the short- and long-term relationships between plants and soil properties. This is an intriguing area of research that couples plant ecology and soil science and should provide valuable information on the interaction of soils with the processes of plant succession and competition. Researchers in this area are urged to be cautious in verifying the assumptions behind popular geostatistical methods and explicit in describing the important steps such as trend analysis, which can reveal critical interpretive information.

Information on soil properties has often been sought for agronomic applications and was obtained from random sampling within defined areas such as plots, fields, and farms. With advancement in the ability to easily and accurately locate sample sites came opportunities for strategic sampling and to portray spatial representations of various soil properties (e.g., Cambardella et al., 1994; Sauer and Meek, 2003; West et al., 1989). Such observations led to an appreciation of the spatial variation of soil properties as a complex product of anthropogenic management practices superimposed on native soil properties. As agronomic systems are typically annual monocultures, individual plant characteristics have a limited effect on the spatial distribution of soil properties. In natural ecosystems, however, the composition, vigor, and maturity of members of the plant community affect competition among species and have potentially profound implications for soil properties.

Bekele and Hudnall (pp. 7–21, this issue) provide an interesting perspective on the spatial

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variation of soil chemical properties in a natural area undergoing transition from prairie to forest. Their focus is on the unique calcareous prairie ecosystem of Louisiana where prairie remnants are being encroached upon by the forest, primarily eastern red cedar (*Juniperus virginiana* L.). Previous work by the same authors (Bekele and Hudnall, 2003) reported on observations of soil organic carbon (SOC) distribution in the same prairie-forest transition zone. Although SOC differences by vegetation type and landscape position were not statistically significant, $\delta^{13}C$ data suggest that the entire site may once have been dominated by prairie vegetation. The current paper focuses on unraveling the relationships between the spatial distribution of pH, EC, and several macronutrients within and between the forest, transition, and prairie vegetation zones.

Vegetation/soil interaction in prairie-forest transition zones

There is a long and rich history of the study of plant and landscape factors associated with prairie-forest transition zones in the U.S. (Anderson, 1987; Curtis and McIntosh, 1951; Pettapiece, 1969; Transeau, 1935). Much of this attention was directed at delineating the spatial extent of native plant cover types at the onset of European settlement and how the distribution of plant communities affected ecosystem functioning and pedological processes. The prairie-forest boundary at the time of settlement has been perceived as a somewhat static boundary; however, the bulk of evidence now suggests that forest and prairie plant communities have advanced and receded across a diffuse transition zone. These changes were largely in response to climatic variables, especially precipitation and temperature, which in turn influenced grazing patterns and the prevalence of fire. As a result, soils under prairie or forest vegetation near transition zones at the time of European settlement have been found to exhibit characteristics associated with the alternative ecosystems (Bailey et al., 1964; Ruhe and Scholtes, 1956; White et al., 1969).

Various factors have been investigated to determine their influence on competition between woody and herbaceous plants including aspect, microtopography, disturbance, and soil pathogens (Aerts, 1999; Matlack, 1994; Mills and Bever, 1998; Peltzer, 2001; Wilson and Tilman, 1993). Competition in natural plant communities has also been differentiated based on nutrient availability (Aerts, 1999). When nutrient and water supplies are abundant, the primary competition is for light. In nutrient-poor environments, however, there is poor consensus on the dominant mechanism with two main opposing views. The first is that successful species are more competitive for nutrients and grow faster at a limiting nutrient availability, and the second, that successful species are those that reduce nutrient losses. Ultimately, a combination of site factors and soil properties produce either a positive or negative feedback on individual plant species, which determines the composition of the plant community.

Eastern red cedar is an aggressive invader species in prairie ecosystems (Briggs and Gibson, 1992; Gehring and Bragg, 1992; Norris et al., 2001) owing to its fast growth, long growing season, large cone crop, production of cones at a young age, high seed-dispersal efficiency, and tolerance of xeric conditions (Axmann and Knapp, 1993; Holthuijzen and Sharik, 1984, 1985; Ormsbee et al., 1976). Once established in prairies, eastern red cedar trees reduce surrounding herbaceous cover primarily by shading (Gehring and Bragg, 1992). Even isolated trees can have a profound effect on soil properties due to fundamental differences between woody and herbaceous plants with regard to the decomposition of organic inputs to the soil. In forest systems, litter-fall on the soil surface is the primary organic input, whereas in prairie systems, the primary organic input is the decomposition of fine roots (Anderson, 1987, Pettapiece, 1969).

Decomposition of moist leaf litter on the soil surface tends to be reasonably rapid and, in the absence of mineral colloids, results in few clay-humus complexes. For these reasons, forest soils are often characterized by a thin, organic-rich O horizon over an A horizon and deeper horizons having relatively low concentrations of clay and nutrients with significant loss of soluble organic components (N, S, and P) and cations (Ca, Mg and K) due to leaching (Anderson, 1987).

Geostatistical methods in soil science

Soil attributes frequently exhibit spatial structure as the outcome of the combined interaction of biological, chemical, and physical processes acting at multiple scales (Parkin, 1993). Geostatistics is a powerful tool for characterization and quantification of spatial variability. The approach is based on the statistical theory of autocorrelation and spatial variability characterization is accomplished using variography. Geostatistical methods have been used to describe and model spatial patterns in soil data for more than 20 years (Burgess and Webster, 1980a, b). Geostatistical analysis has been used to estimate spatial variability of soil physical properties (Viera et al., 1981; Voltz and Goulard, 1994), soil chemical properties (Sauer and Meek, 2003; Yost et al., 1982), soil biochemical properties (Bonmati et a1., 1991; Cambardella et al., 1994), and soil microbiological processes (Aiken et al., 1991; Rochette et al., 1991).

The accessibility of user-friendly geostatistical software packages has increased the use of spatial analysis of soil data, but carries the risk that these tools are used without due consideration of the underlying theory, especially in the field of semivariogram modeling (Goovaerts, 1998) or recommended good practices (see, e.g., Journel and Huijbregts, 1978 or Meek and Sauer, 2004). For instance, in variogram analysis, it is desirable that the underlying data distribution meet Gaussian (normal) assumptions, where departure from normal is minimal, or normality is approximated after appropriate mathematical transformation. Another recommendation is that the intrinsic hypothesis (stationarity of the mean) should be met. If non-stationarity is evident, then data de-trending is recommended prior to performing variogram analysis. The variogram plots can be constructed using all data pairs, including those that represent the maximum extent of the data domain. Variogram models, however, should be estimated using only those data pairs from the smallest lag distance up to a distance that represents half of the domain length, i.e. Journel's Practical Rule (Journel and Huijbregts, 1978). This domain restriction is recommended to provide better parameter estimates for local (small-scale) behavior, since there are more associated data pairs at shorter lag distances. Estimation procedures for variogram models should use a generalized least squares, or similar, approach that includes the pair count at each lag distance in the model calculation (Cressie, 1993).

Bekele and Hudnall were especially interested in investigating any differences in spatial variability among similar sites, and in documenting the scale at which the variability occurs. In order to achieve these objectives, relative semivariograms were developed from soil data taken along several transects that spanned remnant prairie, prairie-forest transition, and forest vegetation. Conventional statistical methods were employed for Exploratory Data Analysis (EDA) prior to the application of variography. EDA revealed that all but one of the soil properties measured was non-normally distributed, and that some or all of the data exhibited a significant trend. The trend was removed by trend surface analysis according to methods described by White et al. (1997). If information on which of the soil attributes sampled from within which vegetation type were de-trended, and the specific model or models used to remove the trend had been included, then it would be possible for the reader to discern just how well the model used to de-trend the data fits the data pattern. This is particularly important since the residual patterns that emerge after de-trending depend to a great extent on the model that is used to de-trend the data. For instance, assume that a polynomial regression model was used to de-trend the data when a segmented-spline line model (Meek et al., 2001) might provide a better fit. The semivariogram developed from the residuals could show a cyclic spatial trend, when in fact, the spatial trend is an artifact introduced through the application of the polynomial model. The possibility exists that some of the most informative and interesting findings of this type of study are missed because of the choice of de-trending model. For instance, the notch points from the segmented-line spline model described above could be used to mathematically delineate boundaries between the transition zone and prairie and forest areas. Such an analysis would provide a spatially congruent predictive tool for identifying the boundary of the transition zone. This is just one example of the opportunities for enhanced data interpretation presented by geostatistical analysis of soils data sets.

Summary

Bekele and Hudnall demonstrate the utility of spatial analysis of soil properties in a unique ecosystem, a study that adds to the breadth of literature regarding geostatistical analyses of soil data. The feedback between plant community composition and species distribution and soil properties in natural systems has promise to provide enhanced insight into the short- and long-term relationships between plants and soil properties. This is an intriguing area of research that couples plant physiological ecology and soil science, and should provide valuable information on the interaction of soils with the processes of plant succession and competition. Researchers in this area are urged to be cautious in verifying the assumptions behind popular geostatistical methods and to be explicit in describing the important steps such as trend analysis, which can reveal critical interpretive information.

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